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Earl Hunt, Marcy Lansman, and Joy Wright
Department of Psychology
University of Washington

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Three experiments are reported that test the generality of attentional theories which postulate that all mental processes compete for a single limited mental resource. We call this general view of inter-task interference the "resource competition" model.

All three experiments made use of the secondary task methodology, in which subjects are required to perform two tasks simultaneously, but are instructed to give one task priority over the other. The resource

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competition model suggests that the secondary task methodology can be used to study individual differences. If subjects can indeed follow instructions concerning the priorities of the two tasks, then performance on the secondary task should be a measure of the "spare capacity" associated with the primary task at a certain level of difficulty and should predict the subject's ability to performn the primary task at a greater level of difficulty.

In the first experiment, the resource competition model was shown to be consistent with the pattern of interference that resulted when a complex reasoning task (the Raven Matrices Test) was combined with a continuous motor task. Performance on the secondary motor task during easier Raven problems predicted subjects' accuracy in solving harder Raven problems.

In the second experiment, it was shown that comprehension of an auditory message and each of two psychomotor secondary tasks competed for capacity. However, subjects were not able to follow instructions concerning the priorities of the two tasks, since the interference resulted in a decrement on the primary comprehension task rather than on the secondary tasks.

In the third experiment, the primary task was continuous paired associate learning and the secondary task involved speed of responding to an auditory probe. Reaction time to the probe during an easy version of the paired associate task predicted performance on a harder version of the paired associate task. However, there were some disturbing inconsistencies between the pattern of reaction times to the auditory probe in this experiment and reaction times to a visual probe in an earlier experiment. These and other results suggested that the resource competition model in some cases fails to account for non-structural interference between tasks.

Some Remarks on Doihg Two Things at Once [1]

Earl Hunt, Marcy Lansman, and Joy Wright
University of Washington

We are interested in how people do more than one thing at a time. This is quite a practical problem. To illustrate its importance one usually refers to situations in which people operate machinery while receiving verbal instructions. The modern Navy certainly has its pilots and air traffic controllers. In the days of John Paul Jones the lookout scanned the horizon instead of a radar screen, and he had to worry about falling out of the rigging. Thus we can look to history to assure us that our research will remain relevant when the fleet once again becomes independent of the fossil fuel supply.

More seriously, our interest in the process of simultaneous task execution has developed from two sources; our interest in the nature of individual differences in information processing (Hunt, 1978, a,b) and Kahneman's seminal discussion of the role of attention of cognition (Kahneman, 1973). Kahneman was able to summarize a wide variety of experimental observations by using a simple model, which we shall call the <u>resource competition model</u>. Its basic assumption is that virtually all "cognitive" tasks draw from the same pool of (rather ill-defined) attentional resources. In order to study situations in which simultaneously executed tasks compete for the same resources, an experimental procedure known as the "secondary task paradigm" has been developed (Kerr, 1973;

Posner and Boies, 1971). In a secondary task study the participant is given a primary and a secondary task, each of which is presumed to draw upon the same attentional resources. The experimental instructions clearly specify that performance level on the primary task is to be maintained, even at the cost of deterioration of secondary task performance. Our interest centers on changes in secondary task performance as the nature of the primary task changes.

Suppose that a person behaves in accordance with a simple resource competition model. Performance on the primary task should be a function of primary task characteristics alone, since the secondary task receives only those resources that are not needed to achieve adequate primary task performance. There should be no qualitative change in the nature of the two tasks when done together or alone, since they compete for resources but do not interact. As the primary task becomes more difficult, overt primary task performance will be maintained by shifting resources from the secondary task. Consequently, performance on the secondary task should deteriorate as primary task difficulty increases, and this deterioration should appear before any deterioration of performance on the primary task. This observation might be of considerable practical importance for it suggests a way of predicting when a person is "about to" make an error on the primary task, before the error actually occurs. This is the point at which we saw a connection between studies of attention and individual differences. Could we indeed use the secondary task methodology to predict when individuals were about the break down on a primary task? If Kahneman's resource competition model is generally true (and Kahneman phrased it in very broad terms indeed), the secondary task methodology might open a broad field in the measurement of both inter- and intra-individual differences in performance on a wide variety of difficult tasks.

Over the past several years there have been very many secondary task and split attention studies. In spite of the generality of Kahneman's original statement of the model, most of the experiments have involved tasks that are more akin to perceptual or motor reaction time studies, or simple short term memory studies, than to what one would naively refer to as "reasoning". Some studies that were reported at these meetings last year are typical (Lansman, 1978). In one study people had to remember 0, 2, or 7 paired-associate items. While they were rehearsing these items, they had to react to a visual probe, which served as the secondary task. In another experiment a memory task was combined with a task in which people had to verify the accuracy of sentences as descriptions of simple pictures. Generalizing rather broadly, both our results and those from other laboratories indicate that the resource competition model is a surprisingly accurate account of most of the data from such experiments. Furthermore, we were able to predict primary task performance at the difficult level from secondary task performance when the primary task was easy. There is, however, a disconcerting result that keeps appearing both in our studies and in those of others. Performance on the primary task is usually affected by the presence of a secondary task. Thus, in spite of the fact that our extension of the resource competition model to individual differences studies appeared frutiful, we had reason to question one of the basic assumptions of the secondary task logic.

In keeping with the traditions of split attention research, we decided to proceed in two directions at once. In one series of experiments we extended the logic of the secondary task paradigm considerably beyond the realm of the typical laboratory paradigms. In these studies, which will be discussed in Experiments I and II, the primary tasks were difficult reasoning and comprehension tasks, while the secondary tasks were psychomotor coordination tasks of varying degrees of difficulty. Thus we asked whether the resource competition model,

and its attendant technology, can be applied to a more complex realm of cognitive activity. We hope you will agree that our results are encouraging. In Experiment III, however, we revisit the more tightly controlled laboratory tasks, and obtain some data that casts more doubt upon the simple resource competition model.

Experiment I: Raven Matrix Problems

The purpose of this experiment was to combine a complex reasoning task using non-verbal stimuli with a simple psychomotor secondary task. Our reasoning was that this seriously tests the resource competition model because the primary task is a very complex, visually oriented task in which reaction times are measured in minutes, and the secondary task is a motor task which involves neither the visual system nor any significant memory load. "Structural" interference should be minimal.

The primary task used was the Raven Matrix Test (Raven, 1965). This is a well-known, carefully standardized non-verbal intelligence test consisting of 36 problems of identical format but widely varying difficulty. By reference to the published data on item analyses (Forbes, 1964), we constructed two parallel forms of the Raven Matrix Set II test (the set normally given to adults). Figure 1 shows an easy item (panel a) and a hard item (panel b). As can be seen by inspecting these problems for just a moment, the difference in difficulty is substantial. Each of our parallel forms of the test contained 18 items. The items were presented in ascending order of difficulty, as is standard for this test. Our presentation was non-standard in two ways. Items were presented via a computer controlled display screen, and only four instead of eight response alternatives were displayed.

The secondary task was a simple psychomotor task that we will refer to as the Gizmo Task. The person had to operate a "Gizmo", which is a simple

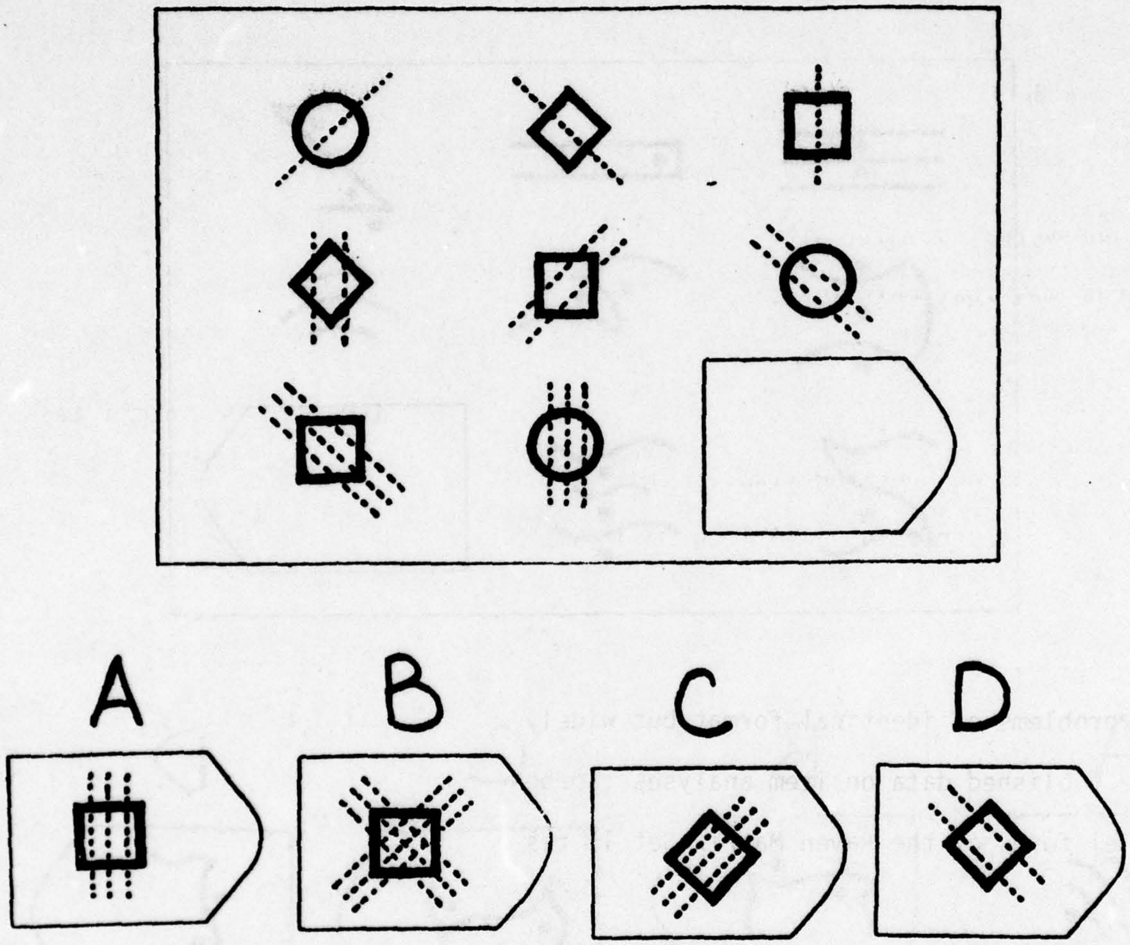

FIGURE 1 a

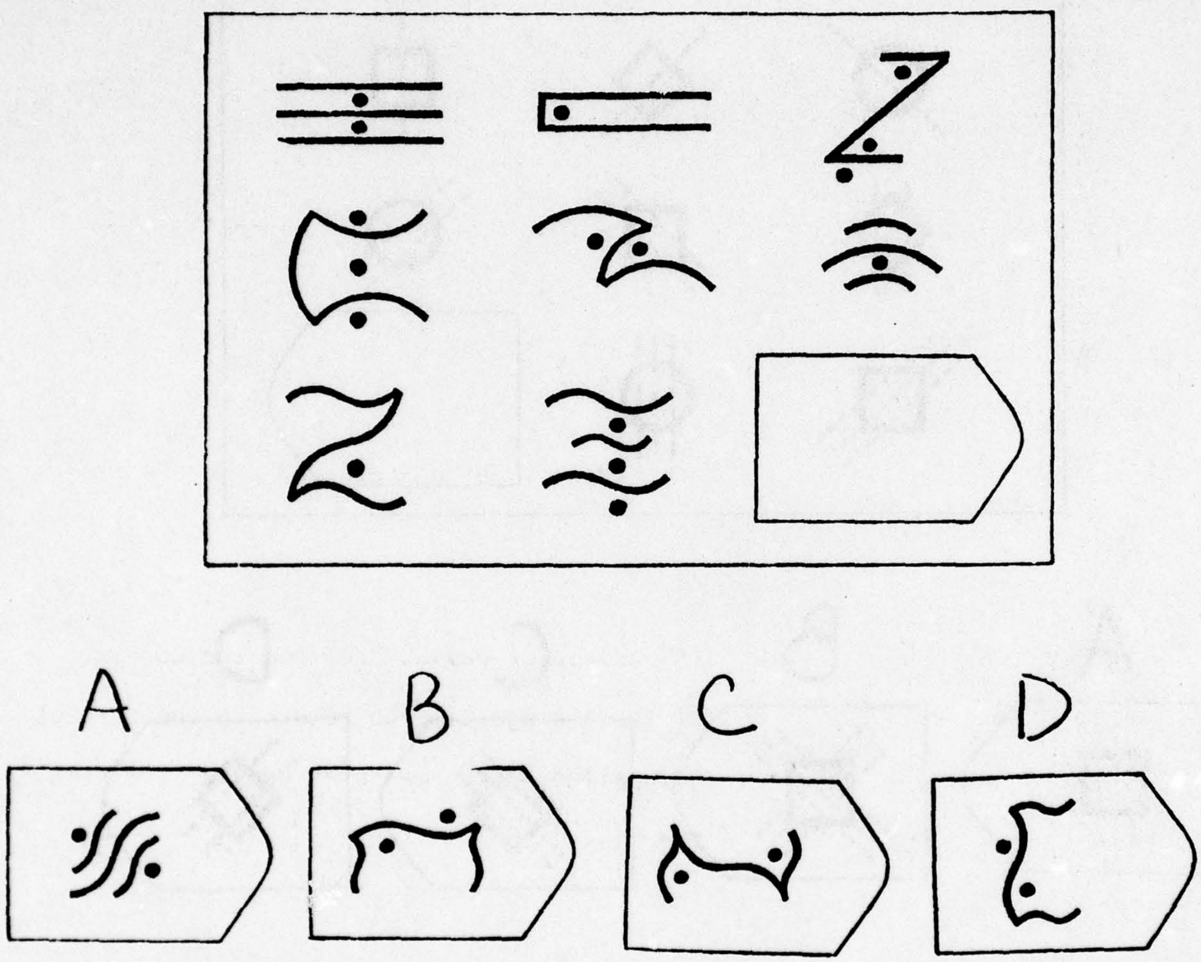

FIGURE 1 b

balance consisting of a lever and a pressure sensing device. The subject had to maintain a light but constant pressure horizontally to the right with the index finger of the left hand. If too much or too little pressure was applied, a tone sounded, indicating that the Gizmo lever was out of position. If the pressure was too heavy, the tone sounded in the right ear; if it was too light, the tone sounded in the left ear.

The experiment involved 52 University of Washington undergraduates. Participants first practiced on the Gizmo, then completed 18 Raven items with the Gizmo deactivated, and then completed 18 items while holding the Gizmo in position.

This experiment allowed us to collect a large number of statistics; only a few will be reported. Raven performance will be indicated by percent of items answered correctly for problems 4-18. (Problems 1-3 were regarded as practice trials for the combined Gizmo-Raven condition.) Gizmo performance can be measured either in terms of the number of deviations from the correct positions, per minute, or in terms of the average time to return to the correct positons after a deviation has been signalled. Both measures provide the same pattern of results. In general, Gizmo performance will be reported in terms of deviation rate, standardized for a particular subject. Thus a positive Gizmo score on a problem indicates that the subject was making more deviations on that problem that he/she normally made. By using standard scores for each subject, we can average across subjects, when appropriate, without being concerned about the (very large) individual differences in absolute Gizmo performance.

Figure 2 shows performance on the Raven test as a function of problem number and presence or absence of the Gizmo task. As expected, proportion of subjects answering an item correctly decreased as problems become harder. Furthermore, proportion correct was smaller when subjects were simultaneously

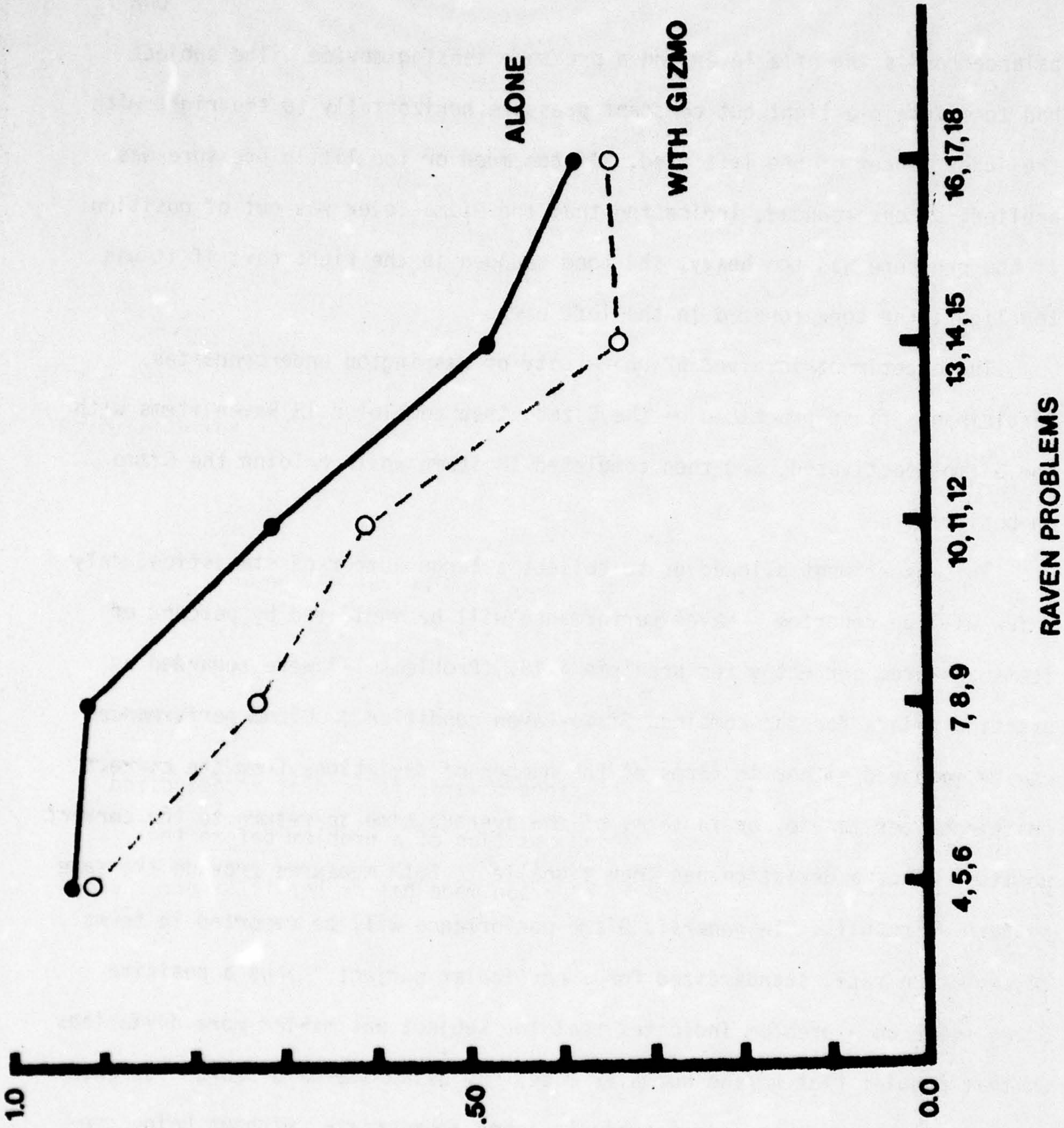
ALONE
WITH GIZMO
RAVEN PROBLEMS
4,5,6
7,8,9
10,11,12
13,14,15
16,17,18
1.0
.50
0.0
p (cor)

FIGURE 2

performing the Gizmo task. There was also a small but significant interaction. Thus we see evidence of resource competition between the primary task and the purely psychomotor secondary task. We also see that people are not able to compartmentalize the tasks neatly into "primary" and "secondary" tasks. Performance on the primary task was adversely affected by the presence of the secondary task.

Figure 3 shows Gizmo and Raven performance in the combined task condition, as a function of problem order. As the primary (Raven) task became more difficult, both Raven and Gizmo performance deteriorated. This again indicates resource competition.

The simple fact of interference does little more than confirm both our intuitions and the results of studies using simpler tasks. What is more interesting is where the secondary task deterioration occurs. Gizmo performance dropped <u>before</u> the subject made any errors on Raven items. There are a number of ways that this point can be made. Perhaps the best conceptual illustration, though not the most straightforward, is to plot standardized Gizmo performance as a function of the position of a problem <u>before</u> the participant's first error. Thus if a person made his or her first error on problem 6, we would plot Gizmo performance on problems 5, 4, and 3 in that order. (There is an analogy between this plot and the plotting of "backward learning curves" in tests of one-trial learning.) Figure 4 shows the data. Gizmo performance is poor immediately before the first error, and gets progressively better as we extend our analysis back 2, 3, 4, up to 7 trials before the first error. Beyond 7 trials the data are apparently unreliable, largely because fewer subjects contributed to the data points. This is shown by the large standard errors for trials preceding the first error by 8 or more.

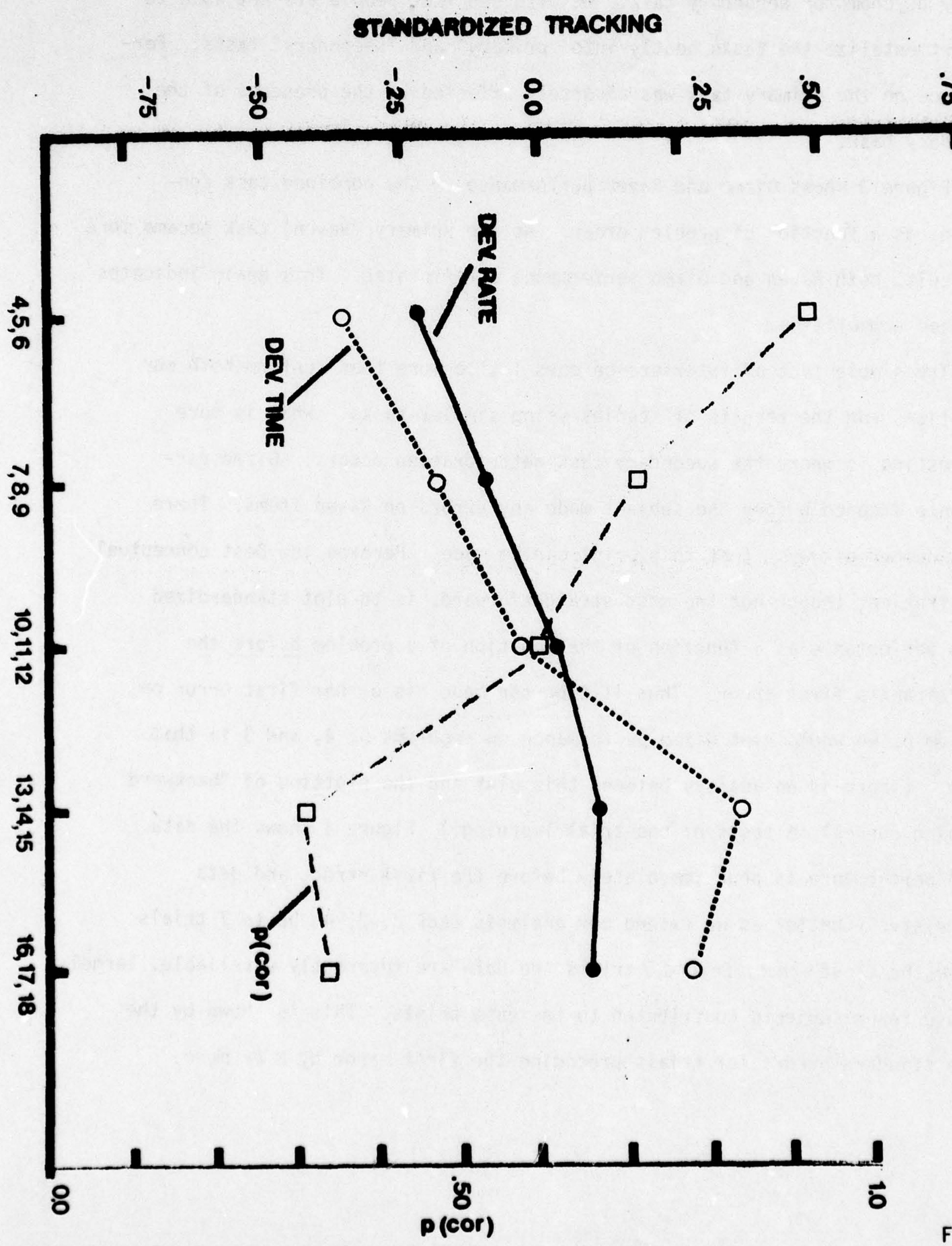
STANDARDIZED TRACKING
-.75
-.50
-.25
0.0
.25
.50
.75
DEV. RATE
DEV. TIME
p(cor)
PROBLEM SETS
4,5,6
7,8,9
10,11,12
13,14,15
16,17,18
0.0
.50
1.0
p (cor)

FIGURE 3

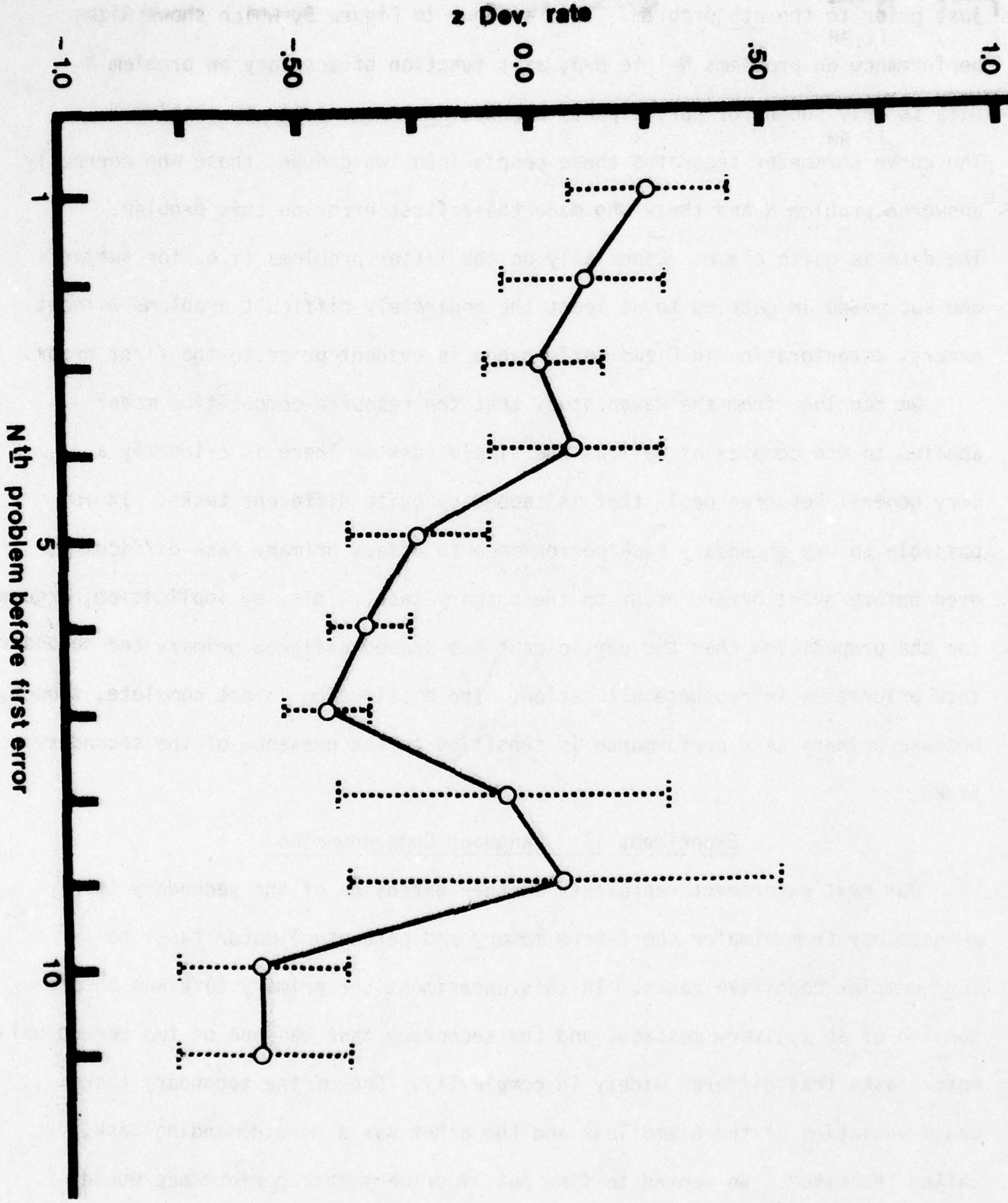

FIGURE 4

The same point can also be made by an analysis of Gizmo performance just prior to the nth problem. This is done in Figure 5, which shows Gizmo performance on problems N-1 to N-3, as a function of accuracy on problem N. Data is only shown for participants who had no errors prior to problem N. The curve parameter separates these people into two groups; those who correctly answered problem N and those who made their first error on this problem. The data is quite clear. Especially on the latter problems (i.e. for subjects who succeeded in getting to at least the moderately difficult problems without error), deterioration in Gizmo performance is evident prior to the first error.

We conclude from the Raven study that the resource competition model applies to the complex as well as the simple tasks. There is evidently a very general resource pool, that is tapped by quite different tasks. It is possible to use secondary task performance to assess primary task difficulty, even before overt errors occur on the primary task. This, by implication, argues for the proposition that the participant has indeed assigned primary and secondary task priorities in resource allocation. The distinction is not complete, though, because primary task performance is sensitive to the presence of the secondary task.

Experiment II: Language Comprehension

Our next experiment represents another extension of the secondary task methodology from simpler short-term memory and perceptual-motor tasks to more complex cognitive tasks. In this experiment the primary task was comprehension of an auditory message, and the secondary task was one of two perceptual-motor tasks that differed widely in complexity. One of the secondary tasks was a variation of the Gizmo Task and the other was a more demanding task, called "Rabbits". We wanted to find out if primary task performance would remain the same regardless of the complexity of the secondary task. The general resource competition model predicts that it would.

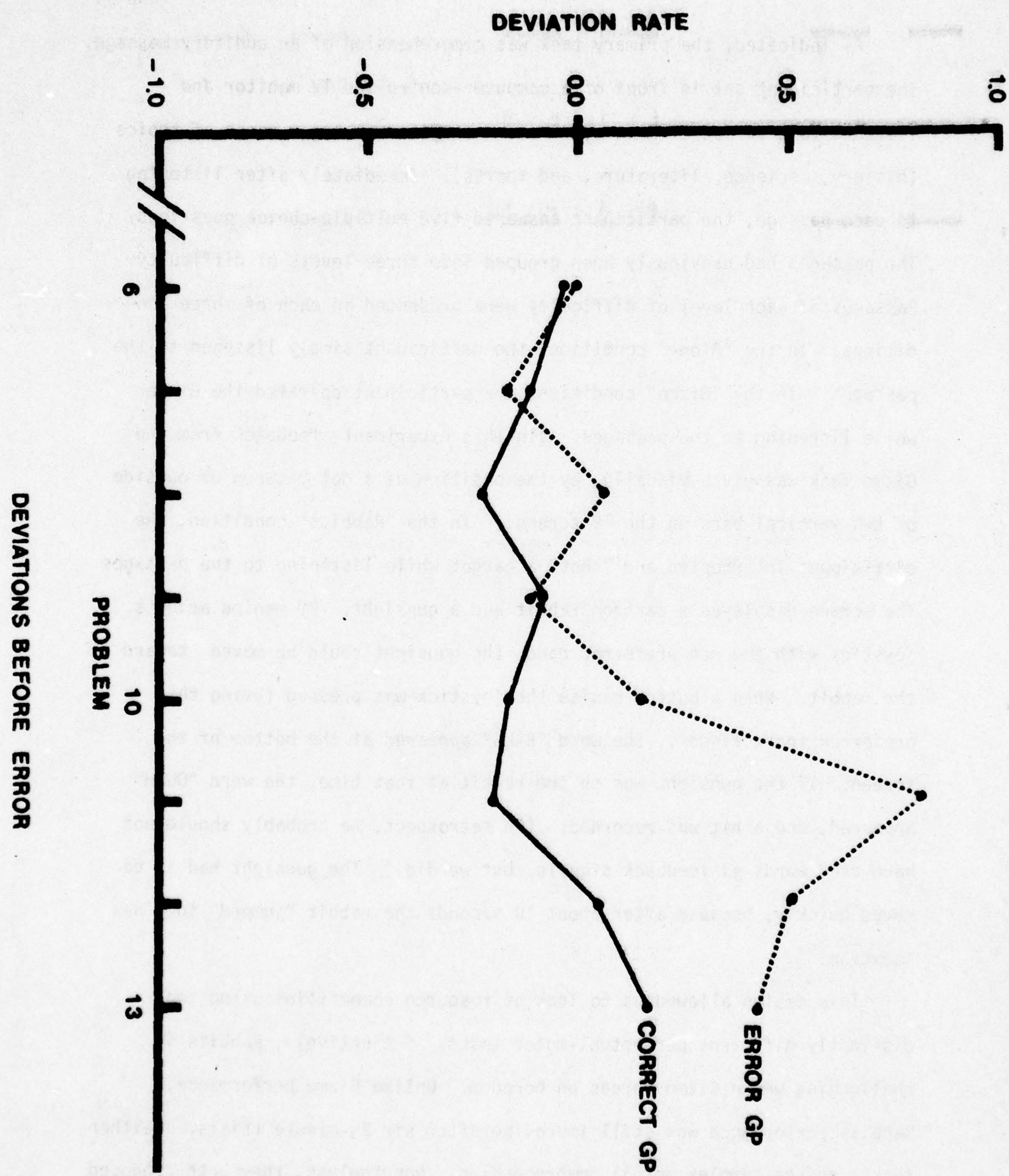
DEVIATION RATE
-1.0
-0.5
0.0
0.5
1.0
6
10
13
PROBLEM
DEVIATIONS BEFORE ERROR
CORRECT GP
ERROR GP

FIGURE 5

As indicated, the primary task was comprehension of an auditory message. The participant sat in front of a computer-controlled TV monitor and listened to a series of 2- to 3-minute passages covering a range of topics (history, science, literature, and sports). Immediately after listening to each passage, the participant answered five multiple-choice questions. The passages had previously been grouped into three levels of difficulty. Passages at each level of difficulty were presented in each of three conditions. In the "Alone" condition, the participant simply listened to the passages. In the "Gizmo" condition, the participant operated the Gizmo while listening to the passages. (In this experiment, feedback from the Gizmo Task was given visually, by the position of a dot between or outside of two vertical bars on the TV screen.) In the "Rabbits" condition, the participant intercepted and "shot" a target while listening to the passages. The screen displayed a cartoon rabbit and a gunsight. By manipulating a joystick with the non-preferred hand, the gunsight could be moved toward the rabbit. When a button beside the joystick was pressed (using the preferred index finger), the word "BANG" appeared at the bottom of the screen. If the gunsight was on the rabbit at that time, the word "OUCH" appeared, and a hit was recorded. (In retrospect, we probably should not have used words as feedback signals, but we did.) The gunsight had to be moved quickly, because after about 10 seconds the rabbit "jumped" to a new location.

This design allowed us to look at resource competition using two distinctly different perceptual-motor tasks. Subjectively, Rabbits is challenging where Gizmo verges on boredom. Unlike Gizmo performance, Rabbits performance was still improving after six 2½-minute trials. Neither task requires complex verbal comprehension. Nonetheless, they both produced

resource competition, which is reflected by a decrement in performance on the primary task. This is shown in Table 1, which presents listening comprehension (measured by proportion correct on the multiple choice items) as function of passage difficulty and type of secondary task.

The main effects of passage difficulty and task condition were significant, $p < .05$. The interaction between the two variables was marginally significant, $.05 < p < .10$. Orthogonal comparisons indicated that, compared to the listening-only condition, comprehension dropped in the dual-task conditions, $p < .05$. There was no significant difference in comprehension between the two dual-task conditions.

Table 2 shows secondary task performance alone and while listening to easy, medium, and hard passages. Gizmo performance is measured by the mean time to return to the correct position and Rabbits by mean number of rabbits hit per minute. An analysis of secondary task performance showed no effect of primary task difficulty on Rabbits performance, and a barely significant effect on the Gizmo, $p < .05$. However, the effect on the Gizmo performance was not in the expected direction. Gizmo performance while listening to an easy passage was slightly better than when the passage was more difficult, but it was also better than no passage at all. In summary, interference between comprehension and the two secondary tasks resulted mainly in a decrement in comprehension. Effects of comprehension on secondary performance were in one case significant, in the other case in the wrong direction. Thus, in a sense, primary and secondary tasks appear to have switched.

	Easy Passage	Medium Passage	Hard Passage	$\bar{x}$
Listening only	.84	.86	.71	.80
Listening with Rabbits	.83	.65	.60	.69
Listening with Gizmo	.82	.66	.71	.73
$\bar{x}$	.83	.72	.67	

Table 1: Mean proportion of multiple-choice comprehension questions answered correctly, classified by passage difficulty and task condition (Experiment II).

	Alone	with Easy	with Medium	with Hard	$\bar{x}$
Rabbits	7.93	7.67	8.13	7.47	7.80
Gizmo	587	381	593	523	521

Table 2: Secondary task performance alone and with passages of varying difficulty. Rabbits performance is measured by mean number of hits per minute. Gizmo performance is measured by mean time in milliseconds to return to the correct position. (Experiment II).

It is surprising that this switch occurred, since in a previous experiment where the modalities of primary and secondary tasks were reversed, the expected primary-secondary task pattern was obtained. The earlier study used reading as the primary task and Gizmo as the secondary task. Gizmo feedback was auditory, as in Experiment I. The results are summarized in Tables 3 and 4. In the dual task condition, reading interfered with Gizmo performance, $p < .05$. The Gizmo, on the other hand, had no effect on reading speed and caused only a slight, but insignificant drop in reading comprehension. Neither the main effect of task condition nor the interaction of task condition with level of difficulty was significant.

Experiment III: Comparison of Two Secondary Tasks

A basic assumption of what we have called the "resource competition" model is that non-structural interference between tasks -- i.e. interference tht does not result from competition for a specific sensory of response mechanism -- results from competition for a general mental resource, variously called "effort", "attention", or simply "mental capacity". In the previous two experiments we tested the ability of this model to explain dual-task interference involving more complex cognitive tasks than have generally been used in attentional research. Experiment III represents a different sort of test of the response competition model. In this experiment, we asked whether different secondary task measures yielded consistent estimates of the spare capacity associated with a given primary task.

	Easy Passage	Hard Passage	$\bar{x}$
Reading only	.89	.78	.84
Reading Combined with Gizmo	.91	.68	.80
$\bar{x}$	.90	.73	

Table 3: Mean proportion of multiple-choice comprehension questions answered correctly, classified by passage difficulty and task condition (earlier unpublished experiment).

Alone	with Easy	with Hard
12.06	15.00	15.72

Table 4: Gizmo performance alone and with easy and hard passages. Dependent measure is mean number of deviations from the correct position per minute (earlier unpublished experiment).

One aim of our research program has been to find out whether, at the level of the individual subject, a measure of the spare capacity associated with a simple version of a task could predict performance on a harder version of the same task. We have hypothesized that if the simple version of a task requires a person's full mental capacity, then that person should perform relatively poorly on a harder version of the same task. Implicit in this reasoning is the assumption that we can talk about spare capacity in this very general sense, i.e. that all effortful mental processes require the same type of attentional resources. If this is true, then the choice of a secondary task measure of spare capacity is somewhat arbitrary. As long as primary and secondary tasks do not involve structural interference, then we should get similar results no matter what secondary task we use.

Recently this assumption has been challenged. For example, Peter McLeod (1978) used a secondary probe reaction time task to measure the spare capacity associated with a sequential letter-matching task. The secondary task involved either a manual or a vocal response to a noise burst. McLeod found that varying the modality of the response changed the pattern of probe reaction times associated with various phases of the primary task. Thus estimates of spare capacity varied with choice of a secondary task.

In view of these and other results showing that various secondary task measures do not always yield consistent results, we felt that it was important to show that our earlier findings using the secondary task methodology could be replicated using a different secondary task. We recently reported an

experiment in which the primary task involved continuous paired associate learning and the secondary task was a keypress response to a visual probe (Lansman, 1978). Here we will discuss a replication of that experiment in which the probe was a tone and the response was vocal.

The general paradigm is illustrated in Table 5. Stimulus items for the paired associate task were letters and response items were single-digit numbers. At the beginning of a trial block, each of the stimulus items appeared paired with a randomly chosen digit (e.g. A = 4). After this initial presentation of letter-number pairs, the trials began. Each trial consisted of a question involving one of the stimulus items (e.g. A = ?), and a new pair involving that same stimulus item (e.g. A = 5). The correct response to a question was the number with which the stimulus item had last been paired. A subject responded to the question by pressing one of eight numbered keys.

In the original experiment, the secondary task probe consisted of four asterisks that appeared during the presentation of new letter-number pairs. Subjects were instructed to press a key as quickly as possible when they saw the asterisks. In the replication, the probe was a tone presented through headphones. Subjects responded by saying the syllable "Bop" into a microphone. Note that the probe occurred during an interval when no response was required to the primary task. Therefore, interference between the two tasks could not be attributed to any kind of response competition. Rather, reaction time to the probe was designed to measure spare capacity associated with rehearsal of the letter-number pairs.

There were five conditions in both experiments:

a) Reaction time control. Here subjects were instructed to ignore the letter-number pairs and only respond to the probes. This provided a baseline reaction time.

Event	Display	Duration
Sequential presentation of initial pairs	A = 7 B = 3	3 seconds 3 seconds
Query. Subject responds by hitting key 3.	B = ?	Subject-paced
Letter just queried is paired with a new number	B = 4	3 seconds
(Tone probe: On 3/4 of the trials in the probe condition, a tone is presented over headphones and the subject says "Bop" into a microphone as fast as possible.)	(Tone) B = 4	(If subject fails to respond to tone within 1.5 seconds, it goes off.)
Query. Subject hits key 7.	A = ?	Subject-paced
Letter just queried is paired with a new number.	A = 5	3 seconds

TABLE 5

b) Easy recall alone. Subjects kept track of two letter-number pairs. There were no probes.

c) Easy recall with probes. Subjects kept track of two pairs and probes occurred during presentation of 3/4 of the new pairs.

d) Hard recall alone. Subjects kept track of seven letter-number pairs. There were no probes.

e) Hard recall with probes. Subjects kept track of seven pairs and probes occurred during presentation of 3/4 of the new letter-number pairs.

In both experiments, the probe stayed on until the subject responded. Subjects were instructed that speed of responding to the probe was of less importance than accuracy of recall, and that they should try not to let the probes interfere with their recall of the pairs. A pay-off system was designed to emphasize the primary-secondary relationship of the two tasks.

Mean reaction time to the probe in the two experiments is shown in Figure 6. In both experiments, reaction time to the probe was considerably slower during rehearsal of the letter-number pairs than in the control condition. When the probes were visual and the response manual, reaction time to the probe in the hard recall condition was significantly slower ($p < .05$) than in the easy recall condition. This is what we would expect if reaction time to the probe reflects spare capacity associated with rehearsal. However, when the probes were auditory and the response vocal, there was no increase in reaction time to the probe from the easy to the hard recall conditions. Instead there was a marginally significant <u>decrease</u> ($p < .10$) in probe reaction time from the hard to the easy condition. This was completely unexpected, since it seemed to us that there should be <u>more</u> interference between rehearsal and a vocal response than between rehearsal and a manual response.

At present we have no explanation for the difference between the results of the two experiments. It is interesting to note, however, that Britton,

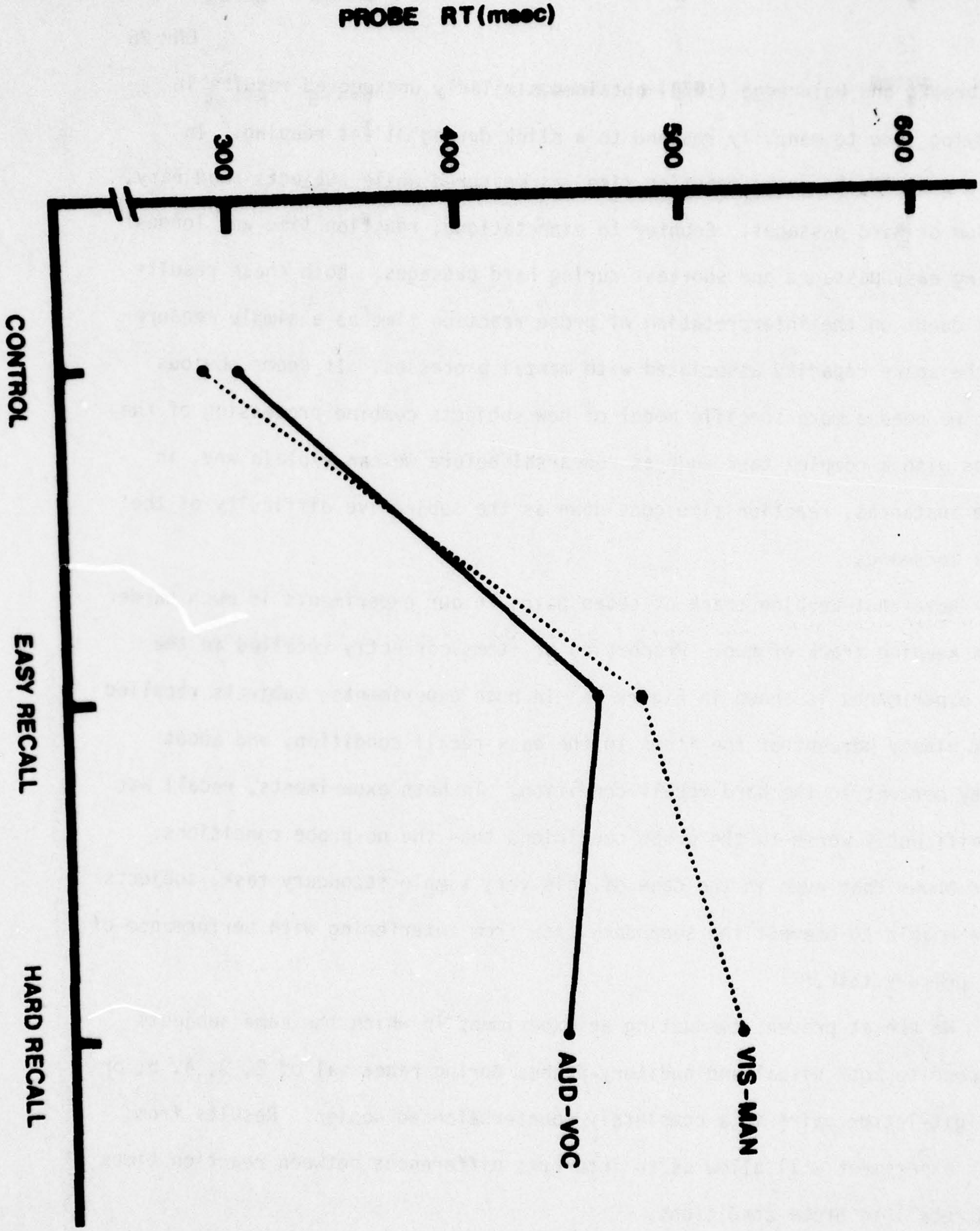
PROBE RT (msec)
300
400
500
600
CONTROL
EASY RECALL
HARD RECALL
AUD-VOC
VIS-MAN

FIGURE 6

Westbrook, and Holdredge (1978) obtained similarly unexpected results in studying time to manually respond to a click during silent reading. In their experiment, probe reaction time was measured while subjects read easy, medium or hard passages. Counter to expectations, reaction time was longest during easy passages and shortest during hard passages. Both these results cast doubt on the interpretation of probe reaction time as a simple measure of the spare capacity associated with mental processes. It seems obvious that we need a more specific model of how subjects combine processing of the probe with a complex task such as rehearsal before we can explain why, in some instances, reaction time goes down as the subjective difficulty of the task increases.

Note that keeping track of seven pairs in our experiments is much harder than keeping track of two. Proportion of items correctly recalled in the two experiments is shown in Figure 7. In both experiments, subjects recalled over ninety percent of the items in the easy recall condition, and about fifty percent in the hard recall condition. In both experiments, recall was significantly worse in the probe conditions than the no-probe conditions. This shows that even in the case of this very simple secondary task, subjects were unable to prevent the secondary task from interfering with performance of the primary task.

We are at present conducting an experiment in which the same subjects respond to both visual and auditory probes during rehearsal of 2, 3, 4, 5, or 7 digit-letter pairs in a completely counterbalanced design. Results from this experiment will allow us to interpret differences between reaction times and recall in probe conditions.

The original aim of these experiments was to find out whether reaction

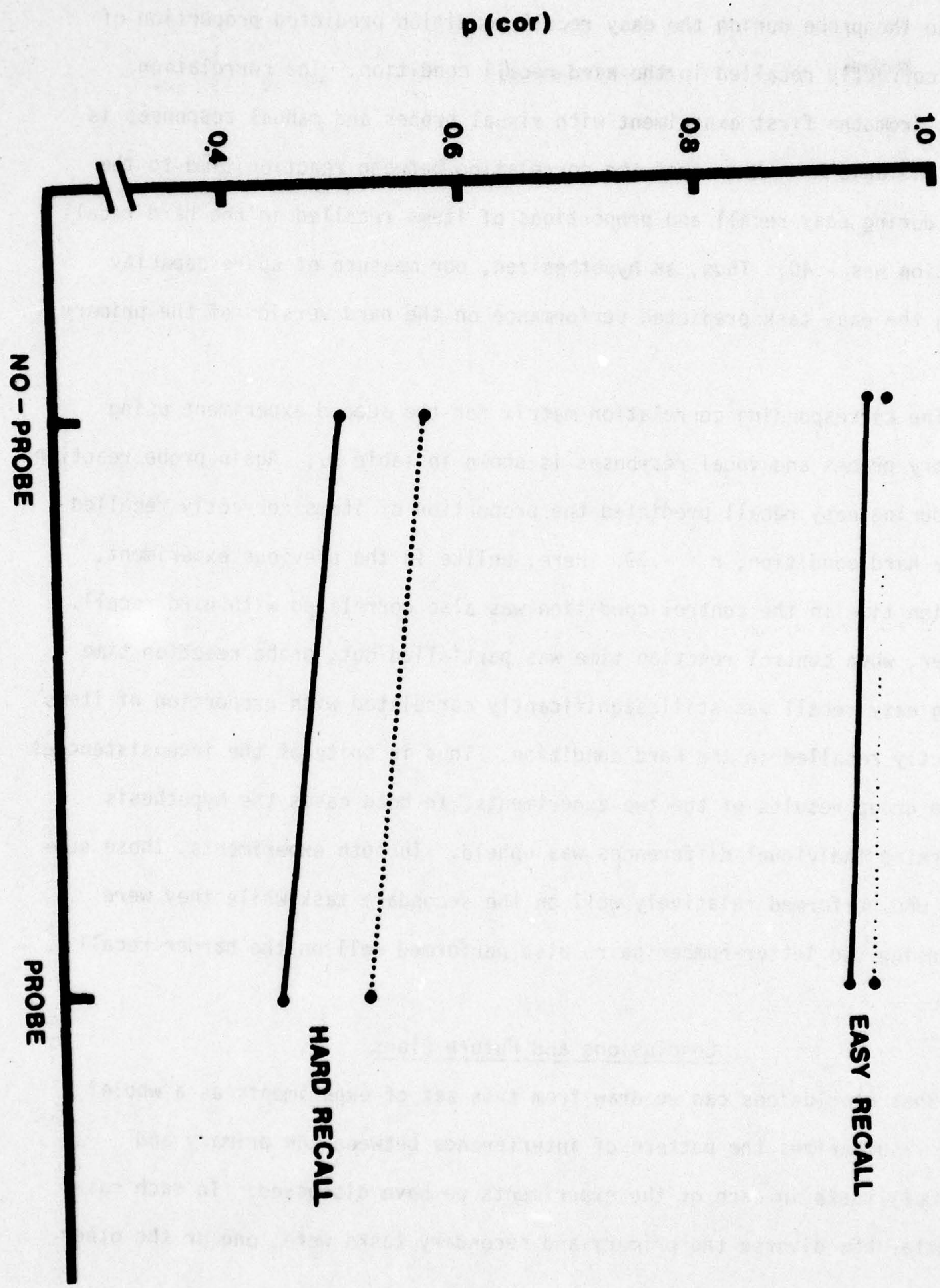

FIGURE 7

time to the probe during the easy recall condition predicted proportion of items correctly recalled in the hard recall condition. The correlation matrix from the first experiment with visual probes and manual responses is shown in Table 6a. Note that the correlation between reaction time to the probe during easy recall and proportions of items recalled in the hard recall condition was -.40. Thus, as hypothesized, our measure of spare capacity during the easy task predicted performance on the hard version of the primary task.

The corresponding correlation matrix for the second experiment using auditory probes and vocal responses is shown in Table 6b. Again probe reaction time during easy recall predicted the proportion of items correctly recalled in the hard condition, $r = -.39$. Here, unlike in the previous experiment, reaction time in the control condition was also correlated with hard recall. However, when control reaction time was partialled out, probe reaction time during easy recall was still significantly correlated with proportion of items correctly recalled in the hard condition. Thus in spite of the inconsistencies in the group results of the two experiments, in both cases the hypothesis concerning individual differences was upheld. In both experiments, those subjects who performed relatively well on the secondary task while they were rehearsing two letter-number pairs also performed well on the harder recall task.

Conclusions and Future Plans

What conclusions can we draw from this set of experiments as a whole? Table 7 summarizes the pattern of interference between the primary and secondary tasks in each of the experiments we have discussed. In each case, no matter how diverse the primary and secondary tasks were, one or the other

Correlations Between Probe RT and Recall Scores

Visual Probe - Keypress Response

		PROPORTION CORRECT	
		Easy Recall	Hard Recall
PROBE RT	Control Condition	-.09	-.05
	Easy Recall Condition	-.27*	-.40**
	Hard Recall Condition	.01	.07

TABLE 6a

Correlations Between Probe RT and Recall Scores
Auditory Probe - Vocal Response

		PROPORTION CORRECT	
		Easy Recall	Hard Recall
	Control Condition	-.13	-.37**
PROBE RT	Easy Recall Condition	-.12	-.39**
	Hard Recall Condition	-.08	-.16

TABLE 6b

or both showed a decrement in performance in the dual task condition as compared to the single task control. Thus at this gross level of analysis, all the experiments supported the resource competition model of attention.

However, upon closer analysis, these experiments revealed two problems with such a model. One problem, evident in the comparison of the two experiments involving continuous paired associates is that different measures of spare capacity can yield different patterns of results. A second problem is that subjects were not able to allocate processing capacity according to the instructions. As shown in Table 7, in the Raven-Gizmo Experiment and in both Continuous Paired Associate Experiments, the primary and the secondary tasks both showed a decrement in the dual task as compared to the single task conditions. In the Auditory Comprehension Experiment, only the primary task showed a decrement, while in the Reading Comprehension Experiment, only the secondary task showed a significant decrement. We must conclude from this variety of results that subjects are often unable to conform to instructions that specify the primary-secondary task relationship. Many experimenters besides ourselves have noticed that subjects find it impossible to prevent the secondary task from interfering with the primary task. However, such problems have generally been ignored by proponents of a general resource competition model of attention (Kahneman, 1973; Norman and Bobrow, 1975). These theorists suggest that subjects can allocate their attention according to the perceived priorities of competing tasks. We propose that an accurate model of dual task performance will have to explain the fact that task characteristics as well as subject strategies influence attention allocation.

In view of these two problems, it seems necessary that we revise some-

Table 7

Experiment	Primary Task	Secondary Task	Dual Task Decrement on Primary?	Dual Task Decrement on Secondary?
Raven with Gizmo	Raven	Gizmo	yes	yes
Auditory Comprehension	Auditory Comprehension	a) Gizmo	yes	no
		b) Rabbits	yes	no
Reading Comprehension	Reading Comprehension	Gizmo	no	yes
Paired Associates w/ Visual Probe	Paired Associate Recall	Manual Response to Visual Probe	yes	yes
Paired Associates w/ Tone Probe	Paired Associate Recall	Vocal Response to Tone Probe	yes	yes

what our general approach to the study of how subjects divide their attention between two competing tasks. We cannot uncritically accept the tenets of the secondary task methodology and assume that such measures as probe reaction time reflect the general mental capacity "left over" while the subject performs the task of interest. Outlined below are two alternative approaches to the study of dual task performance. The first is a relatively non-theoretical applied approach. The second involves a microscopic analysis of a dual-task paradigm that is of particular theoretical interest.

The applied approach is simply to focus on dual task combinations that are of particular practical concern. One such combination involves comprehension of an auditorily presented message while simultaneously performing a complex motor task. The ability to carry out these two functions simultaneously is important in a wide variety of situations ranging from following instructions given by a back seat driver to landing an aircraft under air traffic control. We have shown in Experiment II that in at least one instance, comprehension suffers when combined with a motor task even when subjects are instructed to treat comprehension as primary. What variables affect a person's ability to combine comprehension with a motor task? Characteristics of both the task and the individual are relevant. Task characteristics that could be examined include:

a) Amount of practice the subject has had on the motor task. In the experiments reported here, both the Gizmo task and the Rabbits task were relatively unpracticed. We might very well have obtained different results if we had allowed subjects extensive practice on these two motor tasks.

b) Linguistic structure of the message. Almost certainly various linguistic characteristics of verbal messages influence the liklihood that they can be comprehended while the subject is engaged in a second task.

c) Relevance of the verbal message to the motor task. In the comprehension experiments reported here, the message presented was irrelevant to performance of the motor task. A more interesting and realistic case involves presentation of messages that are necessary for successful performance of the motor task.

d) Priority of the message. The probability that a certain message will be comprehended could be influenced by a signal preceding the message indicating its relative importance.

Turning to individual differences, we need to find out whether skill at verbal comprehension and sill at a motor task are sufficient to predict ability to combine the two tasks, or whether we need to incorporate some measure of time-sharing ability into the prediction equation. Relatively little research has been done on the general question of whether dual-task performance can be predicted by performance on the component single tasks. We reported one experiment in which subjects carried out a dual task involving maintaining a memory load while performing a sentence verification task (Lansman, 1978). In this case, performance in the dual-task situation was highly correlated with single-task performance, suggesting that no time-sharing factor was involved. A similar study might be done in which subject's ability to combine a verbal comprehension task with a motor task is measured.

In following this relatively atheoretical approach, we could ignore such issues as a) Are the two tasks done in parallel, or does the subject switch back anf forth between then? b) What stage(s) of verbal comprehension or motor performance are attention demanding and what stages are automatic? We would not be concerned with precisely <u>how</u> subjects manage to combine the two tasks, only how successful they are. Eventually, however, we would like to arrive at a more theoretical understanding of how people do two things at once. To achieve this, we need to study performance in more controlled situations. We would like to start by examining the secondary probe task more carefully.

Although the probe technique is becoming more and more widely used as a measure of spare capacity, it really not very well understood. When the technique was first used, the predominant model of attention involved a single "limited capacity processor" (Posner & Boies, 1971). A probe, like any other stimulus, required processing by the limited capacity processor before a response could be made. According to this reasoning, the greater the demands placed on the limited capacity processor by the primary task, the longer the probe would need to wait for the processor and the longer the probe reaction time would be.

For more and more attentional theorists, the limited capacity processor is being supplanted by the idea of limited mental resources that can be allocated among various mental processes. Corresponding to this new attentional model is a new explanation for why the response to a secondary probe stimulus is delayed when the subject is engaged in an attention-demanding primary task: Less resources are available for processing the probe.

Neither of these very general models of attention accounts for the inconsistencies between experiments using different types of probes. Both models predict that the pattern of reaction times to different probe tasks should be the same regardless of modality. A further difficulty with either model's explanation of probe delays is that the probe almost always causes a decrement in primary task performance. According to both models, the probe should receive whatever processing capacity is, in a sense, "left over" after the demands of the primary task are met. Yet it is obvious from universally observed primary task decrements that this is not the case.

A model is needed that will give a much more detailed account of how subjects combine primary task processing with response to the probe. Such a model would distinguish between factors that are under that subject's

strategic control and factors that are inherent characteristics of the human information processing system. We seem to assume, for example, that instructing the subject to consider the probe task secondary will influence his behavior. This suggests that the subject can make a conscious decision concerning the amount of resources to allocate to the probe when it occurs. Yet there is little evidence that the subject actually can set the priorities of the primary and secondary task. If the delay in responding to the probe is associated with delays in detection, then perhaps instruction concerning priorities are irrelevant.

A research effort to answer these questions has less immediate application to real-life situations than a program of the first type described here. But it would seem to be a necessary first step in solving some of the paradoxes that have resulted from an uncritical acceptance of the assumption of the secondary task methodology. We feel that eventually such an effort would result in better methods for the study of individual differences in the ability to do two things at once.

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